How much white space has the FCC opened up?

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***Abstract*—USA Census data from 2000 is used to estimate the white space available for cognitive radios in TV bands in the continental USA. The FCC's November 2008 ruling is analyzed to show there are roughly nine white-space channels available on average per person given the currently active television stations. The analysis also demonstrates the conservatism of fixed threshold sensing rules for white-space detection — the -114dBm rule for sensing ATSC signals is expected to recover less than one white-space channel on average per person.**

I. Introduction

In its order released on November 14, 2008, the FCC allowed cognitive radio operations in 'white spaces' within the TV bands [1]. Technologists, regulators, business strategists and economists are all interested in the amount of spectrum this has made available. The FCC rules are based on the idea that cognitive radios should only operate in locations/channels where they will not create harmful interference to TVs. To actually estimate the recoverable spectrum for average users requires considering the real-world distribution of TV transmitters and potential whitespace users.

We assume that the transmitters in both the FCC high power TV database [2] and the master low power database[1] are transmitting [3] and neglect some of the minor clauses from the FCC ruling[2]. Only fixed devices were considered in this analysis. These devices can use channels 2, 5–36 and 38-51. Standard ITU wireless propagation models [4] are used. The US Census data of 2000 lists the population by zip code [5]. The zip code is also specified as a polygon [6], and we assume the population is uniformly distributed[3] within that polygon. To keep to the strict page limits here, most of the details and conceptual insights are deferred to [7].[4]

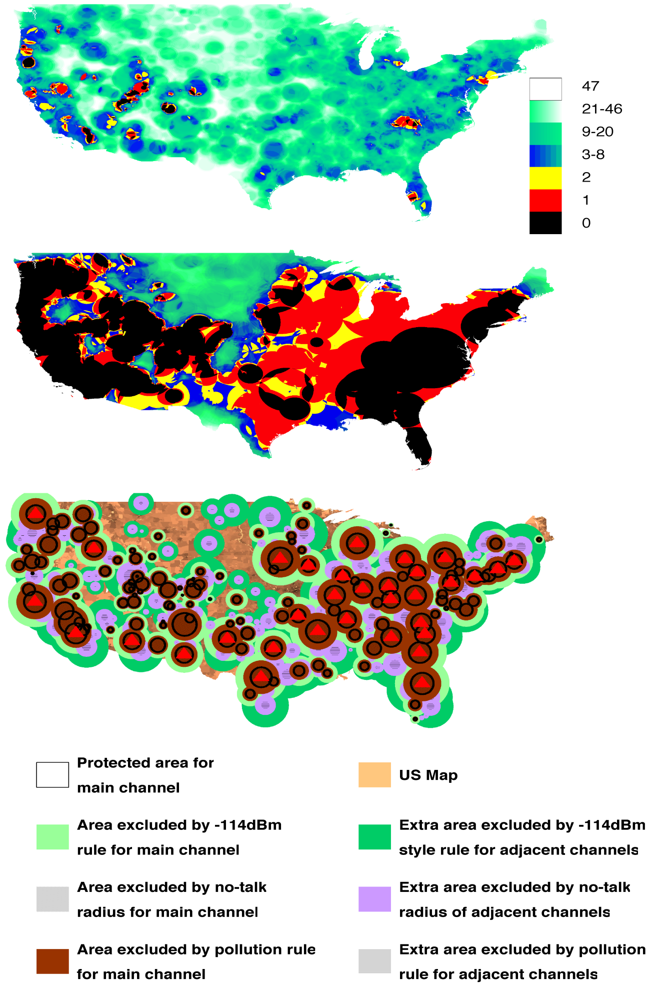


Fig. 1. Visual representation of the available white space channels at each location based on the FCC's geo-location rules (top map) and sensing rules in the typical case (middle map). Visual representation of the available white space for channel 39 using various usage guidelines (bottom figure). We consider a channel where the TV transmission effectively raises the noise floor by 5dB to be polluted. Notice that pollution dominates protection within the channel while it is the other way around for adjacent-channel considerations.

II. The Results

The FCC approach sets the protected radius r_p at the protected contour. The no-talk radius (r_n), which is the distance from the transmitter where the secondary is not allowed to transmit, is calculated by adding the protected radius to the interference radius $(r_n - r_p)$. The FCC specifies the value of the interference radius as 14.4km for co-channel operation and 0.74km for adjacent channel operation. It is important to note that $r_n - r_p$ is specified as a fixed distance that should be used irrespective of the channel frequency (See Section 15.712

[1]The low power list was compared with the FCC database of 08/15/09 using the facility ID. Only low power transmitters that are present in the FCC database are added to the final list.

[2]We neglected wireless microphones and the more stringent emission requirements for the 602-620MHz bands (Section 15.709 [1]). We also neglected the locations of cable headends, fixed broadcast auxiliary service (BAS) links, and PLMRS/CMRS devices (Section 15.712 [1]). We believe that the neglected clauses will result in only a minor change to these results.

[3]So we are ignoring both the diurnal variation in population as many people commute to work and school as well as the finer structure of where residences are within each zip code.

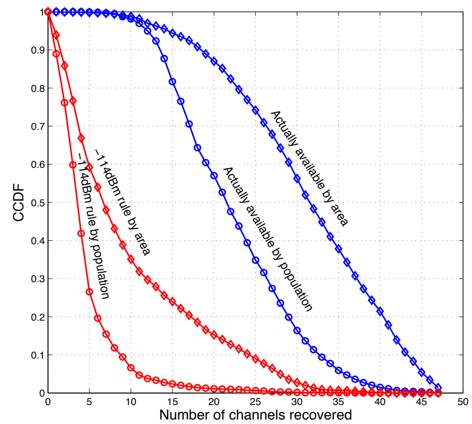
[4]All data files, Matlab code and automated scripts to generate the tables and graphs of this paper and in [7] can be found at [8].

in [1])[5]. The details of using this methodology to calculate available spectrum are given in [7]. Table I shows the white space available using the FCC definitions. These calculations were performed for a 4W, 30m (HAAT) secondary transmitter. More channel may be available for low power devices. The high UHF bands are included only for completeness, but these have been shifted away from television use and so do not constitute useable whitespace. An interesting feature of Table I is a contrast between the number of channels available by location versus that available by person. In the 'By Area' calculations we assume that all people are uniformly distributed across the US while in the 'By Population' calculations we factor in the actual densities per zip code as per the US Census of 2000. Since existing broadcast television towers have been installed to provide coverage to high population areas, excluding the area around each tower yields the loss of many people.

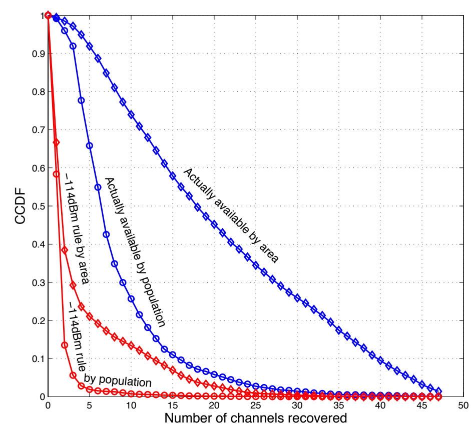
The FCC has demanded a detection sensitivity of -114dBm for ATSC signals for cognitive radios that cannot determine their location and query an authorized geolocation database. Such a detection rule has to be conservative in order to protect TV receivers in worst-case fading scenarios. However, in the typical case, such a rule tends to loose a significant portion of the white space [9]. To evaluate the amount of white space recovered by the -114dBm rule we determined the distance at which the signal dropped to the -114dBm level for 50% of the locations, 50% of the time (F(50, 50) rule)[6]. From Table I it is clear that the -114dBm rule reduces the available white space by a factor of three on an area basis. This effect is even more dramatic when white space by population is considered. In this case the available white space is reduced by a factor of seven.

The impact of the -114dBm rule is apparent by comparing the top two maps in Figure 1. The top map in Figure 1 shows the average number of channels per location as per the FCC's geo-location rules while the map in the middle shows the same for FCC's sensing rules. With sensing most locations will typically see no white-space channels, assuming the propagation models used here are accurate.

The bottom map in Figure 1 shows the relative area lost by various rules. As discussed earlier, sensing loses significant area as shown by the light and dark green circles. This map also contrasts the FCC's protection viewpoint (a secondary can only transmit where it does not interfere with the primary) and the pollution viewpoint (a secondary will only transmit where the pollution from the primary is "low enough"). For the purposes of this figure, "low enough" is defined as interference that is no more than 5dB above thermal noise in the main channel and 55dB above thermal noise in adjacent channels. The slanted lines mark out the area lost due to the FCC's geo-location rule for co-channel usage while the brown circles mark the area lost to co-channel pollution. The figure makes it clear than the 5dB pollution viewpoint typically dominates the protection viewpoint. The opposite is true for adjacent channels – the 55dB pollution rule is significantly less stringent than the FCC's adjacent channel protection rule.



(a)



(b)

Fig. 2. Probability of getting at least a given number of channels using FCC style geolocation and fixed threshold (-114dBm) rules for uniform and actual population densities. (a) Adjacent channels are ignored. (b) Adjacent channels are considered

Simple averages can only tell us so much. Figure 2 shows the probability of getting at least a given number of white space channels using different detection rules. This enables estimates of the nationwide commercial quality of service that can be offered to white-space users. For example, even if we need only two channels to be available, we can ensure this for less than 15% of the population using the FCC's -114dBm-style rule.

III. Prior work in estimating available white space

There has been prior work in estimating the amount of white space available[7], but this has usually been done by lobbyists.

[5]This requirement is more intended for fixed white space devices.

[6]A cognitive radio user might be expected to adjust the sensing antenna so as to catch the worst fades (remember: if the signal decays below -114dBm the user *can* use the channel). But such maneuvering cannot be performed for all transmitters and channels simultaneously.

[7]In [10], we had some plots containing estimates similar to the ones presented in this paper. The key difference is that those were made assuming the television station distribution *before* the transition to digital television and assumed that every analog station would just switch over to ATSC, but stay on the same band. The present analysis is more realistic in that it accounts for the actual TV transition to digital.

Detection Scheme	By Area				By Population			
	LVHF 2,5,6	HVHF 7-13	LUHF 14-51	HUHF 52-69	LVHF 2,5,6	HVHF 7-13	LUHF 14-51	HUHF 52-69
Geolocation ([1] Section 15.712)	2.4	4.13	23.8	16.4	2.5	3.24	16.1	15.9
Geolocation with adjacent channels	2.17	2.35	14.9	14.7	2.21	1.1	5.82	13.3
-114dBm rule	0.985	0.409	7.7	13.8	1.13	0.167	2.57	13.6
-114dBm rule with adjacent channels	0.631	0.0505	2.63	9.83	0.639	0.004	0.284	8.87

TABLE I

COMPARISON OF THE AVERAGE NUMBER OF WHITE SPACE CHANNELS AVAILABLE PER USER IN VARIOUS FREQUENCY BANDS USING THE METHODOLOGY SPECIFIED IN THE FCC REPORT FOR A 4W 30M TALL TRANSMITTER. THE TOP TWO ROWS USE THE DEFINITION OF $r_n - r_p$ FROM SECTION 15.712 IN [1] WHILE THE NEXT TWO ROWS DEAL WITH SENSING-BASED RULES. THE -114DBM SENSING RULE FOR CO-CHANNELS TRANSLATES INTO A -110DBM SENSING RULE FOR ADJACENT CHANNELS.

The problem is that both the language and methodology used by previous work does not properly distinguish between the pollution and protection viewpoints and this is the source of much confusion. There is even variation among those that focus on protection.

In [11], Snider estimates that the average amount of white space available per person is 214MHz. This is based on the FCC's estimate that the average American can receive 13.3 channels and hence the remaining 35.7 (214 MHz) are deemed available for white space use. This approach grossly overestimates white space since it disregards the fact that the no-talk radius is not the same as the protected contour and ignores the reasonable adjacent channel protection mandated by the FCC.

New America Foundation also has another estimate of the amount of white space available in major cities [12]. This study similarly overestimates the amount of white space (for example, they assume that 19 white space channels will be available in San Francisco). Since their methodology for computing available white space has not been described, we cannot explain the discrepancy between our paper and [12].

In [13], the authors claim to use the actual population data to quantify the amount of white space available under different scenarios. However, a closer examination of the methodology reveals that the authors are, in fact, assuming a uniform population density. The authors estimate the size of each census block to be around 16 square miles. Each census block contains an average of 1300 people. For each transmitter the number of people in its protected contour can be estimated by taking the number of census blocks that fit into its protected contour times 1300 – a methodology that leads to an implicit uniform population density assumption. Their estimate of the median bandwidth per person for scenario X (all Digital TV, Class A stations and TV translators; co-channel rules only) to be ∼180MHz while our estimate of the median bandwidth per person assuming uniform density is 186MHz . Similarly for scenario Z (all Digital TV, Class A stations and TV translators; co-channel and adjacent channel rules) they estimate the median bandwidth to be ∼78MHz while our estimate of the median bandwidth is ∼102MHz. The slight discrepancy in these cases is due to the fact that [13] uses the the now obsolete FCC NTSC/ATSC database which yields a much higher number of towers – 12339 versus 8071.

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